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EVALUATION OF A PRE-ACTIVATED SEALANT SELF-SEALING CONCEPT FOR PROTECTING AIRCRAFT FUEL TANKS AGAINST SMALL ARMS PROJECTILES

ELASTOMERS AND COATINGS BRANCH
NONMETALLIC MATERIALS DIVISION

SEPTEMBER 1975

TECHNICAL REPORT AFML-TR-75-22
FINAL REPORT FOR PERIOD DECEMBER 1972 – JUNE 1973

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This research was directed by Messrs. T. L. Graham (AFML/MBE) and J. K. Klein (ASD/ENJPF) under Project No. 7340, "Nonmetallic and Composite Materials," Task No. 734005, "Elastomeric and Compliant Materials." This evaluation was conducted during the period December 1972 to June 1973.

This technical report has been reviewed and is approved for publication.

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This investigation was conducted to evaluate the merits of a novel self-sealing materials concept proposed by Dynamic Science Division of Ultrasystems Inc. that offers the potential of sealing cored or misaligned wound punctures beyond the capability of conventional self-sealing fuel cells developed in the past. The concept is based on pre-activated sealant which is in a pressurized state and thus, flows into and fills a cored-out or misaligned wound. In this case, a mechanical technique for placing a fluid sealant under pressure was

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ABSTRACT (Continued)

investigated. The required test panels were prepared by mechanically injecting a fluid sealant silicone elastomer into the interstices of a quilted fabric panel construction and curing it to the desired consistency while applying pressure. Results of ballistic tests involving .50 caliber AP, API, and Ball M2, .60 caliber Ball and 20mm TP projectiles validated this self-sealing materials concept's capability for sealing cored projectile wounds. On the strength of these encouraging preliminary ballistic test results, the Aeronautical Systems Division has initiated a program to further exploit the pre-activated sealant approach for improved self-sealing fuel cells in protecting aircraft against destruction by small arms projectiles.

FOREWORD

This report covers work performed under a joint materials evaluation by the Elastomers and Coatings Branch, Nonmetallic Materials Division, Air Force Materials Laboratory, and the Fuel and Hazards Branch, Power Division, Directorate of Propulsion and Power Engineering, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

The research was supported by the Air Force Materials Laboratory Director's Funds and equipment furnished by the Aeronautical Systems Division.

The program was directed by Messrs. T. L. Graham (AFML/MBE) and J. K. Klein (ASD/ENJPF) under Project No. 7340, "Nonmetallic and Composite Materials," Task No. 734005, "Elastomeric and Compliant Materials." This evaluation was conducted during the period December 1972 to June 1973.

The authors are indebted to Mr. J. O. Crouch for technical assistance during the gunfire evaluation and report preparation, to Mr. J. Conner and Mr. W. Polley for their support in preparation of the test articles and support during the gunfire testing, and to the Air Force Flight Dynamics Laboratory range personnel for their fine assistance in conducting the tests.

The items tested were experimental items that were not developed or manufactured to meet Government specifications. The items were procured on a "best effort" basis for evaluation. Any failure to meet the technical goals of the study is no reflection on the manufacturer.

TABLE OF CONTENTS

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LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION I
INTRODUCTION

A novel concept for self-sealing fuel cells has been advanced by Dynamic Science Division of Ultrasystems, Inc., which offers a possible superior materials approach for protecting aircraft fuel tanks from destruction by small arms projectiles. The claimed theoretical advantage (United States Patent No. 3,664,904, dated 23 May 1972) of this novel materials concept is its potential capability to seal cored-out and misaligned wounds inflicted by activated incendiary and high explosive projectiles. Such a capability would be significantly beyond the capability of the mechanical and chemical material systems exploited in the past (References 1 - 4). The concept is based on a pre-activated sealant which is in a pressurized state so that it will flow and fill a cored-out material wound puncture inflicted by activated incendiary projectiles or jagged fragment emitted by explosive projectiles.

Two approaches were used in fabricating self-sealing material composites where the sealant is in an activated (pressurized) state. In one case, plies of structural fabric impregnated with a fuel impermeable rubber are sewn to form a continuous channel quilted pattern. A fluid sealant rubber material is then injected into the quilted channel structural pattern, pressurized when completely filled and subsequently, cured to the desired consistency. The other approach involves sewing a partially cured layer of natural rubber between plies of fuel permeable fabric. After this material sandwich composite is sewn into a square-patch quilted pattern, additional plies of fabric impregnated with a fuel impermeable elastomer are added for reinforcement. When exposed to fuel the pockets of sealant swell and are held in a pressurized state by the restraining forces exerted by the confining layers of fabric until punctured.

The standard type of self-sealing fuel cell material composite is similar in construction. It utilizes a layer or layers of partially cured natural rubber sealant in an unpressurized state. Although it has proven to be very effective for sealing slit type wounds, repeated ballistic tests have shown this general type of materials composite to be ineffective for sealing cored-out material wounds.

Considering the ultimate unique potential benefits of the concept, AFML Director's Funds were requested and provided to purchase test panels for conducting preliminary gunfire tests to assess the merits of this new self-sealing materials concept.

The nature of the self-sealing materials composite panels procured, their performance under gunfire, and the recommendations made regarding future work in this materials area are discussed in detail in this report.

SECTION II
DISCUSSION

1. DESCRIPTION OF TEST PANEL MATERIALS AND METHODS OF FABRICATION

As previously stated, there are two approaches for preparing pressurized sealant elastomeric self-sealing materials constructions. In either case, the sealant constituent is restrained (held in a pressurized state) by plies of resilient layers of fabric sewn together in a quilted pattern. The mechanically pressurized sealant fabrication technique was used in the preparation of the test panels procured for this preliminary feasibility self-sealing performance evaluation.

The basic construction consisted of four plies of square woven (basket weave) nylon structural fabric with a 42 by 42 thread count which weighs 11.9 ounces per square yard. The two inner plies were connected by parallel, linear rows of stitching spaced 3/16 of an inch apart with five stitches to the inch. Single strand Dacron thread rated at 25 pounds strength was used to minimize creep. Spacing (7/64 of an inch or less) was provided between the inner plies for subsequent injection of the sealant. The two stitched plies and one additional ply on each side were impregnated with a solvent solution of Adiprene L-100 (a polyether-based urethane) and cured at elevated temperature to drive off the solvent.

The sealant employed was a low viscosity, room temperature curing dimethyl silicone polymer commercially sold by General Electric as RTV 615. It is a two-component system which utilizes chloroplatinic acid as the curing catalyst. The concentration of catalyst was adjusted to produce a cured gummy sealant material which flows under pressure but is immobile in the unpressurized state at the temperature extremes encountered by subsonic aircraft. In this case, 0.35 parts chloroplatinic acid per 100 parts polymer appeared to produce a cured sealant with the desired rheological characteristics.

In preparation of the test panels the fluid sealant was injected through a small copper tube (about 3/32 of an inch in O.D.) into the quilted construction which was evacuated to eliminate air pockets. When filling is completed, the sealant is placed under the desired static pressure. The sealant in eight of the ten panels procured for this preliminary investigation was pressurized to a gauge pressure of 120 psi. The sealant in the remaining panels was pressurized to a gauge pressure of 150 psi. After sealing the fill tube to hold the sealant under pressure, each of the panels were heated in an oven to 210 to 250°F for 24 hours to cure the encased pressurized sealant.

A few years ago, Dynamic Science developed and gunfire tested panels prepared using the fuel swelling sealant activation approach with the aid of U.S. Army Aviation Laboratory. Although the results of these ballistic tests (Reference 5) were favorable, it was felt that the above type of sealant and fabrication technique offered certain advantages over the partially cured natural rubber fuel activated sealant approach. The advantages cited (Reference 6) in favor of the sealant injection-pressurization technique utilizing the fluid RTV silicone polymer as the sealant were:

1. The interstitial pressure and rheology characteristic of the silicone sealant are controlled independently.

   a. The interstitial pressure is controlled by adjusting the pressure applied to the sealant after injection is completed.

   b. The rheological nature of the silicone polymer sealant can be regulated over a wide range by varying the type and concentration of the compounding ingredients.

2. Like the natural rubber sealant, the candidate silicone sealant is inherently tacky and readily swells in contact with jet fuel to aid the seal forming process.

3. In contrast to the natural rubber based sealant, the silicone type sealant is functional over a broader temperature range.

   a. The estimated functional temperature range of the natural rubber sealant is -40 to 250°F.

b. Silicone polymers, in general, exhibit elastic characteristics at temperatures as low as -65°F and are oxidatively stable at temperatures in excess of 400°F.

The self-sealing pressurized sealant materials composite, as determined on a section cut from one of the test panels, weighs roughly 1.3 lbs/sq ft and is about 1/4-inch thick. This construction is somewhat heavier and thicker than the improved .50 caliber standard self-sealing fuel cell materials construction which weighs about 0.86 lbs/sq ft and has a thickness gauge of about 0.18 inches.

Like the standard type self-sealing fuel cell, the pre-activated sealant self-sealing fuel cell construction requires the support and protection of a backing board material. The backing board material used in this investigation was Goodyear's ARM-018 (4 ply) composite board which weighs approximately 0.49 lbs/sq ft and is about 0.097 inches in thickness.

2. GUNFIRE TESTING

a. Test Setup and Procedures.

The test panels were mounted on the front and back of a reinforced steel cube structure (approximately 37 inches x 32 inches x 33 inches), so that an entrance and exit wound evaluation could be made for each shot. Several different test configurations were employed as shown in schematic form in Figures 1 - 4. The test tank was filled with red, 25 pores per inch (ppi) reticulated polyurethane foam manufactured by the Scott Paper Company to prevent explosion of the test article. JP-4 jet fuel was used for all testing and an analysis of this fuel is provided in the appendix. The aromatic content of the fuel was 12.2%. The testing was performed at the Ballistic Impact Test Facility of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The test tank was placed on the horizontal gunfire range with a carbon dioxide fire extinguishing system located above the test article to provide protection against any fire which might develop by ignition of the fuel from activation of incendiary rounds. Figure 5 is a picture of the

test setup on the range. All testing was conducted at a distance of 38 feet from gun to test article such that the path of the bullet was perpendicular to the test panel. Fuel temperatures varied from 39 to 49°F and the test article was fueled at the start of each day's testing to 3/4 full (30 inches).

b. Gunfire Shot Descriptions and Results

Four sets of test panels were evaluated. The test setups, types of projectiles involved, and the results obtained are discussed in detail below:

(1) Test Series 1: Low Pressure Sealant Panels, .50 Caliber APM2 Projectile Threats, Shots 1 and 2.

The configuration of the test setup is shown in Figure 1. A set of panels with the sealant under 120 psig pressure was used. The two shots fired into this test cell were .50 caliber armor piercing AP M2 projectiles. These shots (Figures 6 and 7) struck the panels at 4 inches and 6.5 inches below the fuel surface and there were no fires. The wounds inflicted by the first shot did not seal within the two-minute time period designated by MIL-T-5578. However, the entrance wound exhibited some sealant flow and looked as if it was trying to seal. Figure 8 shows the fuel continuing to seep (note fuel stain) from this small cored hole wound. The second shot sealed at the entrance but not at the exit where there was a large two-inch tear.

(2) Test Series 2: High Pressure Sealant Panels, .50 Caliber APIM8 (Functioned and Non-functioned) and .50 Caliber Ball M2 Projectile Threats, Shots 3 - 7.

The sealing capability of panels with the sealant pressurized to 150 psig was tested by Shots 3 - 7. Shots 3 and 4 were .50 caliber armor piercing incendiary API M8 nonfunctioned projectiles. The test setup configuration is shown in Figure 2. An aluminum 2024-T3 sheet, .063 inches thick, was used to simulate aircraft skin in this test cell assembly. Shot 3 sealed at both entrance and exit while Shot 4 sealed at entrance only. The shots struck the panel at 5 inches and 6 inches, respectively, below the fuel surface and there were no fires. Shots 5 and 6 were .50 caliber armor piercing AP M2 and .50 caliber ball M2 projectiles. Shot 5 sealed at the entrance but neither entrance nor exit sealed at Shot 6. An aluminum 2024-T3 sheet, .090 inches thick,

was placed in front of the test article for Shot 7 as a striker plate to function the projectile and yellow, 15 ppi reticulated polyurethane foam (Scott Paper Company) was placed in the gap between the aluminum sheets to simulate an aircraft cavity foam installation, (Figure 3). This shot was a .50 caliber armor piercing incendiary API M8 projectile. There was no fire and there were no seals during the first two-minute observation period. However, it was noticed that both entrance and exit wounds had sealed after about 15 minutes. Figure 9 shows the entrance and exit panel wounds for Shots 3 - 7 while Figure 10 shows the damage done to exit backing board material and aluminum sheet by these shots.

(3) Test Series 3: Low Pressure Sealant Panels, .50 Caliber APM2, .50 Caliber APIM8 (Functioned) and .60 Caliber Ball Projectile Threats, Shots 8 - 10.

Test panels with the sealant under 120 psi pressure were used for test Shots 8 through 10. Figures 11 and 12 show the entrance and exit panel wounds for Shots 8 - 10. Shot 8 (.50 caliber APM2 projectile) was conducted with the setup shown in Figure 2. The bullet struck the test panel at approximately five inches below the fuel surface, and no seals occurred during the observation period. The test cell setup was modified as shown in Figure 4 for Shot 9. This round was .50 caliber APIM8 (functioned) projectile and despite the lack of cavity foam there was no fire. The bullet struck at six inches below the fuel surface and a seal at the exit was observed. Figure 13 shows the fuel leaking from the entrance wounds inflicted by Shots 8 and 9 while Figure 14 shows the damage to the exit cell wall before the tenth shot was fired. Shot 10 (.60 caliber ball) was fired into the setup shown in Figure 2. The shot hit the test panel at approximately ten inches below the fuel surface. There was very severe leakage and the energy transfer was such that the steel chain retaining the test cell broke. Figure 15 shows the tremendous damage caused by Shot 10, the .60 caliber shot. Figure 16 shows the exit panel for the .60 caliber shot wound with the material pulled back to reveal the quilt stitching pattern.

(4) Test Series 4: Low Pressure Sealant Panels, .50 Caliber Ball M2, .50 Caliber APIM8 (Functioned), and 20 mm TP Projectile Threats, Shots 11 - 13.

A third set of test panels with the sealant under 120 psig pressure were tested. The test configuration for Shots 11 and 13 is shown

in Figure 2, while Figure 4 shows the test configuration for Shot 12. Shot 11 was a .50 caliber ball M2 projectile, Shot 12 was a .50 Caliber APIM8 projectile, functioned, and Shot 13 was a 20 millimeter target practice round. The bullets struck the test article at approximately 7.5 inches, 7 inches, and 12.5 inches respectively below the fuel surface. There were no fires. Only the entrance wounds for Shots 11 and 12 sealed. The entrance panel and backing board wounds caused by Shots 11 - 13 are shown in Figure 17. Figure 18 shows the damage to exit test panel and backing board for these shots. Shot 12 exited in the vicinity of the exit wound inflicted by the previous shot, producing a single large tear wound in both the test panel and the backing board. The 20mm round (Shot 13) caused severe damage. Figure 19 shows the heavy stream of fuel leaking from the entrance wound inflicted by this projectile.

3. ANALYSIS OF GUNFIRE TEST RESULTS

The test panels were closely examined after removal from the test cube assemblies. Table 1 provides a description of the damage. Exit wall test panels suffered more damage than entrance wall test specimens. Entrance wounds inflicted by the .50 caliber projectiles (Table 2) generally sealed or the fuel leak was not more than a seep. Although the self-sealing reliability of this system was not good for the cored wounds and the misaligned slit wounds, fuel leakage in many instances was limited to a seepage type leak (Table 3). The panels containing sealant pressurized to 150 psig proved to be slightly more effective in sealing wounds inflicted by .50 caliber projectiles (Shots 3-7) than the test panels wherein the sealant was under a pressure of 120 psig. The damage inflicted by the .60 caliber and 20mm ball projectiles was catastrophic (Figure 15 and 19).

For the most part, the backing board appeared to provide good support. Due to the inadequate support provided by the tank stiffeners, there were instances, as indicated above, where the backing board suffered tear damage and did not provide the support needed to keep the slit wound in alignment. The quilted pattern construction fabricated to confine the pressurized sealant exhibited good tear resistance in spite of the lack of support.

The sealant was responsive and flowed into the wound area. It was not, however, adequate for sealing gap wounds. Table 4 presents the overall sealing performance of the materials. While not every shot sealed, the feasibility of the material to provide sealing action was confirmed. Several days after the test panels had been gunfired, it was noted that the sealant was draining out of the panels through the wounds. The viscosity of the sealant draining from the panels was much lower than the sample of the cured sealant provided in closed containers. Suspecting that the sealant may have reverted because of poor hydrolytic stability, a sample of sealant provided in the closed container was exposed to a 95% relative humidity at 200°F. After a couple of weeks exposure under these accelerated conditions, the sealant showed no sign of reversion which ruled out hydrolytic instability. The effect of fuel on the sealant was also investigated. Its only effect was to swell the sealant. It is conjectured that the mechanical shock of the impacting projectile may have caused this slightly crosslinked semisolid sealant to revert to a more fluid consistency.

SECTION III
CONCLUSIONS AND RECOMMENDATIONS

1. Results of preliminary ballistic tests demonstrated that the quilted self-sealing materials composite is capable of sealing cored wound punctures inflicted by small arms projectiles. The need for further improvement in the performance of the materials involved was also evidenced by the gunfire results. Specifically, the proper balance between sealant flow and viscosity must be established. Overall the results have been sufficiently encouraging to warrant further examination in a "scaled-up" program.

2. Of the two approaches investigated (since 1970), the fuel activation technique for pressurizing the sealant is preferred. More assurance is needed that the sealant in the area surrounding the wound is in a compressed state for adequate sealant flow without washout. On the basis of this observation, it is recommended that future development efforts concentrate on the fuel swelling approach for providing self-sealing of multiple cored-out and misaligned material wounds inflicted by small arms projectiles and high explosive missile fragments.

3. The technique wherein a fluid sealant is injected into the interstices of a preformed quilted fibrous reinforced construction, mechanically pressurized, and subsequently cured to the desired consistency is viewed as an alternative approach for achieving the technical objective. However, this approach is considered to be a greater development challenge with regard to the injection process, material fabrication, and multiple impact capability.

4. The ballistic tests indicated that the silicone polymers could be used successfully as a sealant with the quilted fibrous composite materials. With the inherent temperature advantages of the silicone materials, it is concluded that an optimized silicone sealant could be used successfully to meet the technical goals.

TABLE 1

DAMAGE DESCRIPTION

Shot No.	Entrance	Exit
1 (.50 CAL AP)	.50 inch hole-very slight coring	2-1/16" long slit - some chunking, no coring
2 (.50 CAL AP)	.50 inch hole - no coring	2" long slit - no coring
3 (.50 CAL API)	.50 inch hole - no coring	2" long cored wound
4 (.50 CAL API)	.50 inch hole - no coring	1-1/2" long cored wound
5 (.50 CAL AP)	.50 inch hole - no coring	2" long wound - no coring
6 (.50 CAL BALL)	.50 inch hole - no coring	1-3/8" long cored wound
7 (.50 CAL API)	.50 inch hole - no coring	1-3/8" long cored wound
8 (.50 CAL AP)	.50 inch hole - no coring	2" long - wound misaligned
9 (.50 CAL API)	.50 inch hole cored	1-1/8" long wound - no coring
10 (.60 CAL BALL)	.60 inch hole cored	approx 4" long wound - misaligned
11 (.50 CAL BALL)	.50 inch hole - no coring	2" long - no coring
12 (.50 CAL API)	.50 inch hole - part of jacket lodged in wound	1-1/4" long - wound misaligned
13 (20 mm TP)	.75 inch hole - badly cored	badly cored

TABLE 2
GUNFIRE TEST LEAKAGE DESCRIPTION

SHOT NO.	THREAT	ENTRANCE	EXIT
1	.50 CAL AP	Very Slight Seep	Medium Heavy Seep
2	.50 CAL AP	Damp Seal	Medium Heavy Seep
3	.50 CAL API	Dry Seal	Damp Seal
4	.50 CAL API	Damp Seal	Heavy Seep
5	.50 CAL AP	Dry Seal	Medium Heavy Seep
6	.50 CAL BALL	Medium Heavy Seep	Medium Stream
7	.50 CAL API*	Medium Heavy Seep	Medium Heavy Seep
8	.50 CAL AP	Medium Seep	Medium Heavy Seep
9	.60 CAL API*	Very Heavy Seep	Damp Seal
10	.60 CAL BALL	Medium Stream	Very Heavy Stream
11	.50 CAL BALL	Damp Seal	Heavy Stream
12	.50 CAL API*	Damp Seal	Heavy Stream
13	20MM BALL	Very Heavy Stream	Medium Heavy Stream

*Functioned

TABLE 3

PERFORMANCE AGAINST CORING/CHUNKING

Shot 1 Entrance	.50 AP	Very Slight Seep
Shot 3 Exit	.50 API NF	Damp Seal
Shot 4 Exit	.50 API NF	Heavy Running Seep
Shot 6 Exit	.50 BALL	Medium Stream
Shot 8 Entrance	.50 AP	Medium Seep
Shot 9 Entrance	.50 API F	Very Heavy Seep
Shot 10 Entrance	.60 BALL	Medium Stream
Shot 13 Entrance	20mm BALL	Heavy Stream (Gusher)
Shot 13 Exit	20mm BALL	Medium Heavy Stream
Shot 1 Exit	.50 CAL AP	Medium Heavy Seep

PERFORMANCE AGAINST MISALIGNMENT

Shot 8 Exit	.50 CAL AP	Medium Heavy Seep
Shot 10 Exit	.60 CAL BALL	Heavy Stream (Gusher)
Shot 11 Exit	.50 CAL BALL	Heavy Stream
Shot 12 Exit	.50 CAL APIF	Heavy Stream

APINF - Armor Piercing Incendiary Nonfunctioned
APIF - Armor Piercing Incendiary Functioned

TABLE 4

SEALING PERFORMANCE BY THREAT

	ENTRANCE	EXIT
.50 CAL API Functioned 3 shots	1 Seal	1 Seal
.50 CAL API Non-functioned 2 shots	2 Seals	1 Seal
.50 CAL BALL 2 shots	1 Seal	0 Seal
.50 CAL AP 4 shots	2 Seals	0 Seal
.60 CAL BALL 1 shot	0 Seal	0 Seal
20mm BALL 1 shot	0 Seal	0 Seal

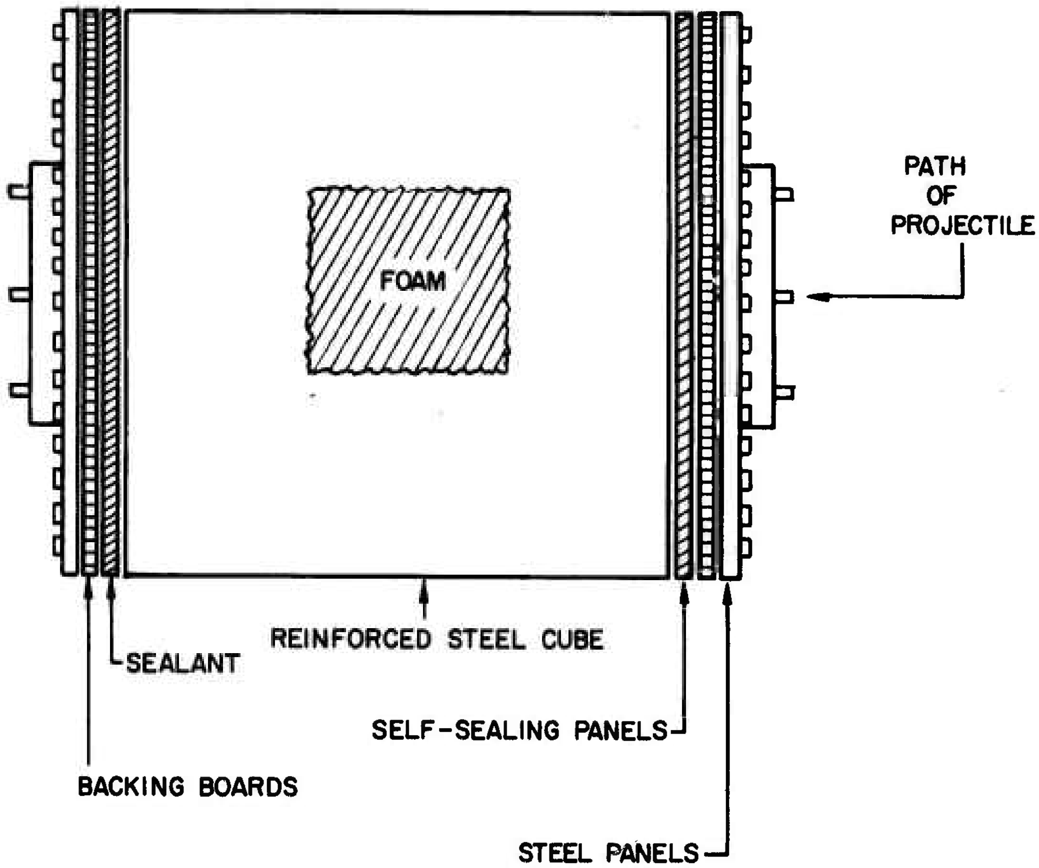

Figure 1. Test Cell Configuration No. 1

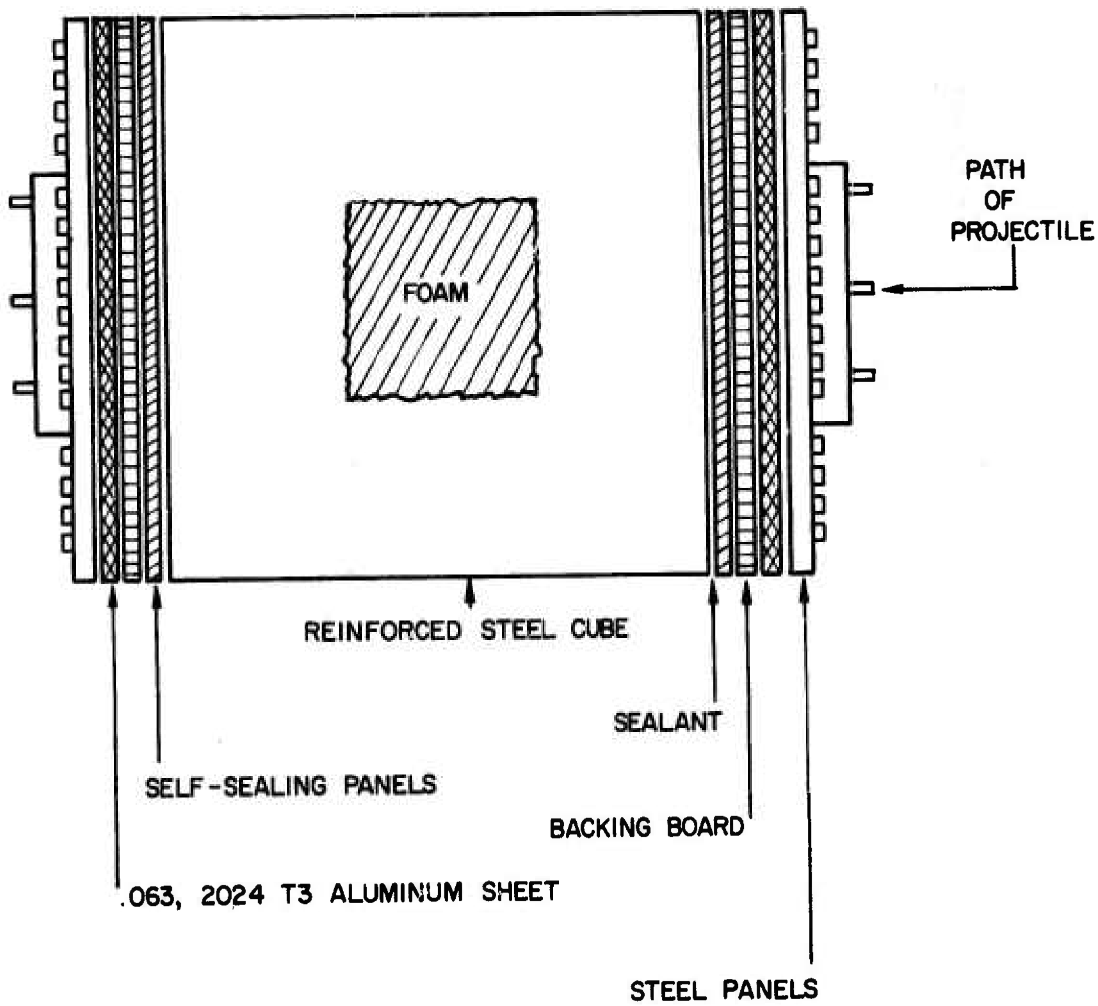

Figure 2. Test Cell Configuration No. 2

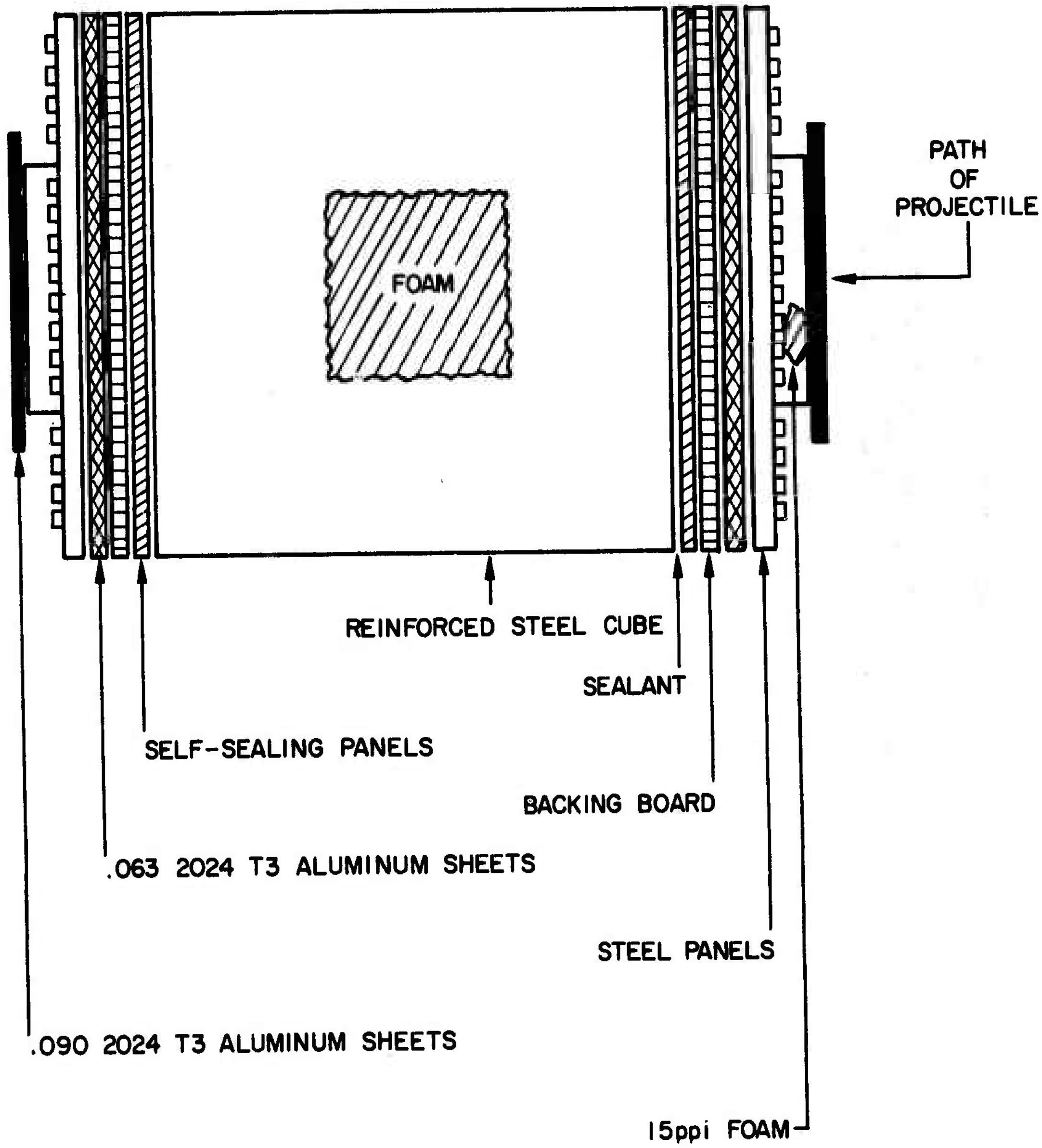

Figure 3. Test Cell Configuration No. 3

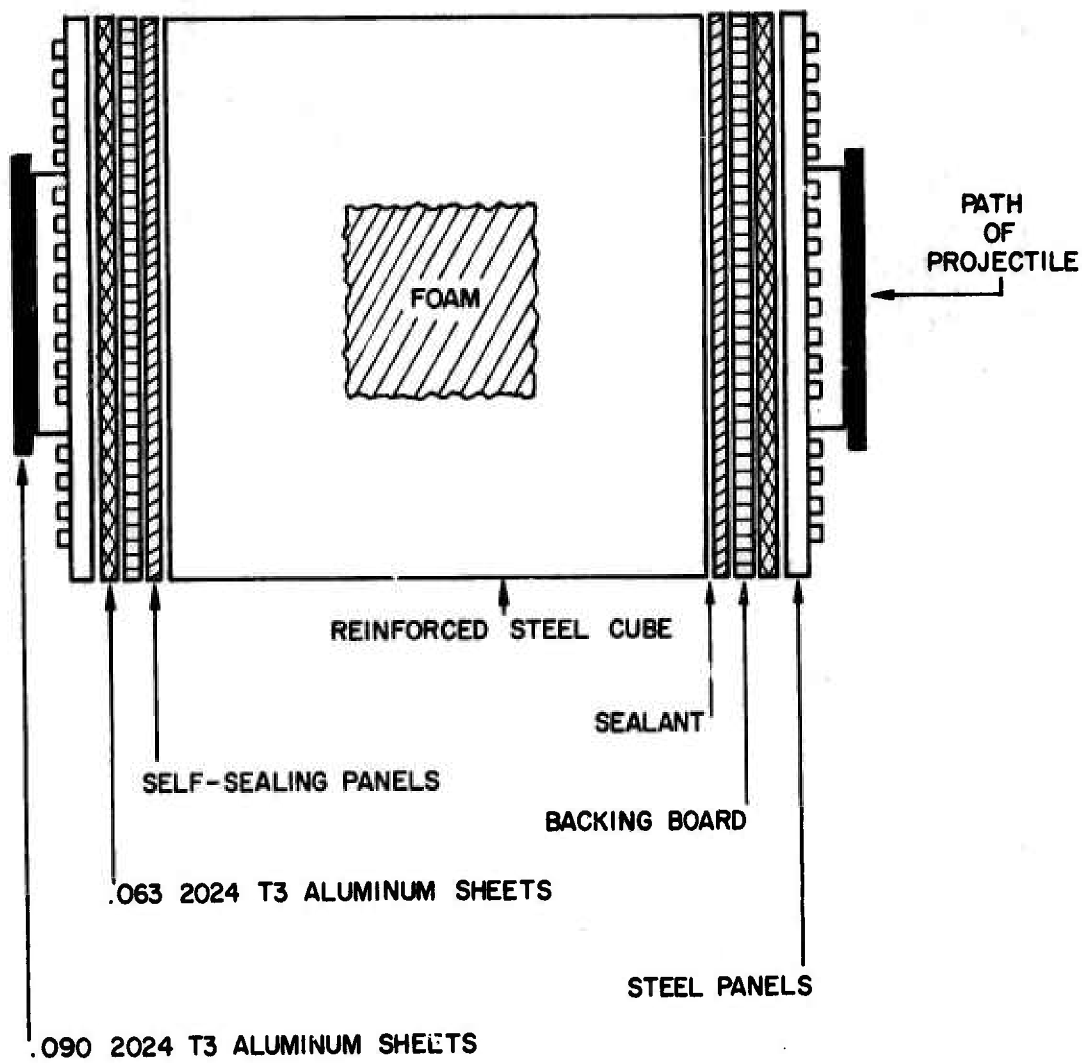

Figure 4. Test Cell Configuration No. 4

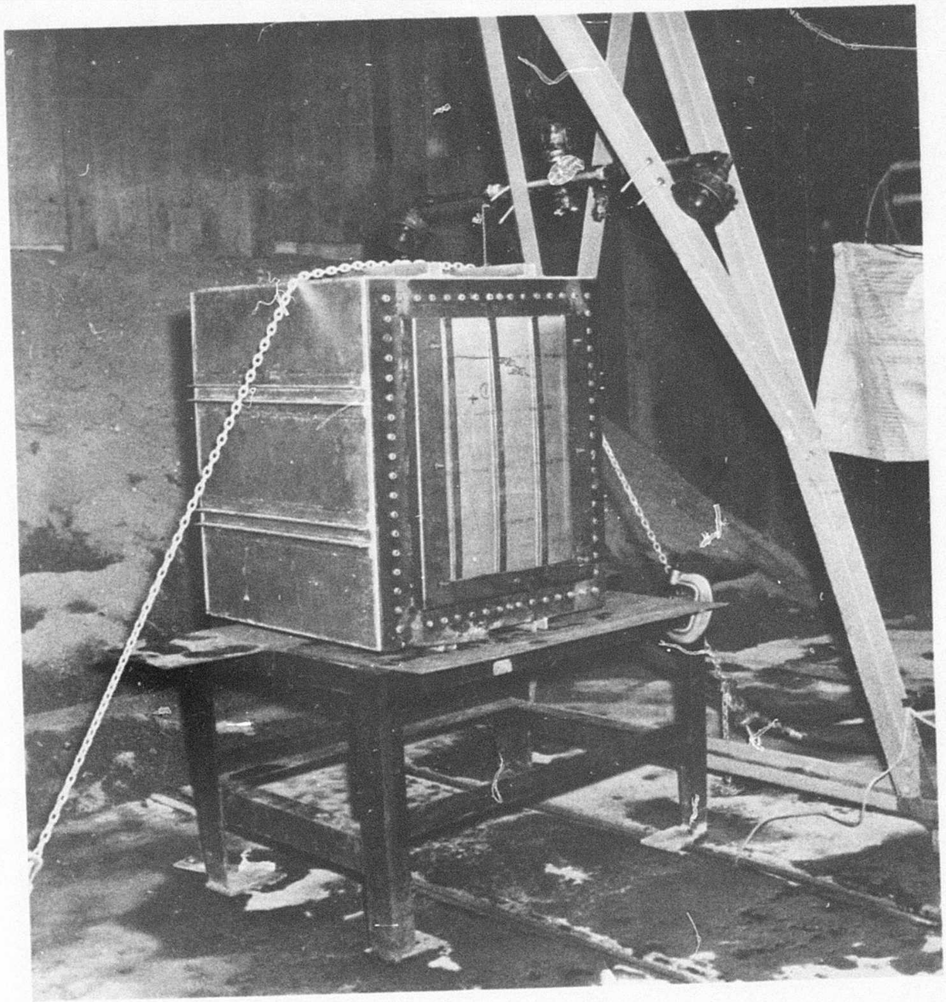

Figure 5. Gunfire Test Setup on Range

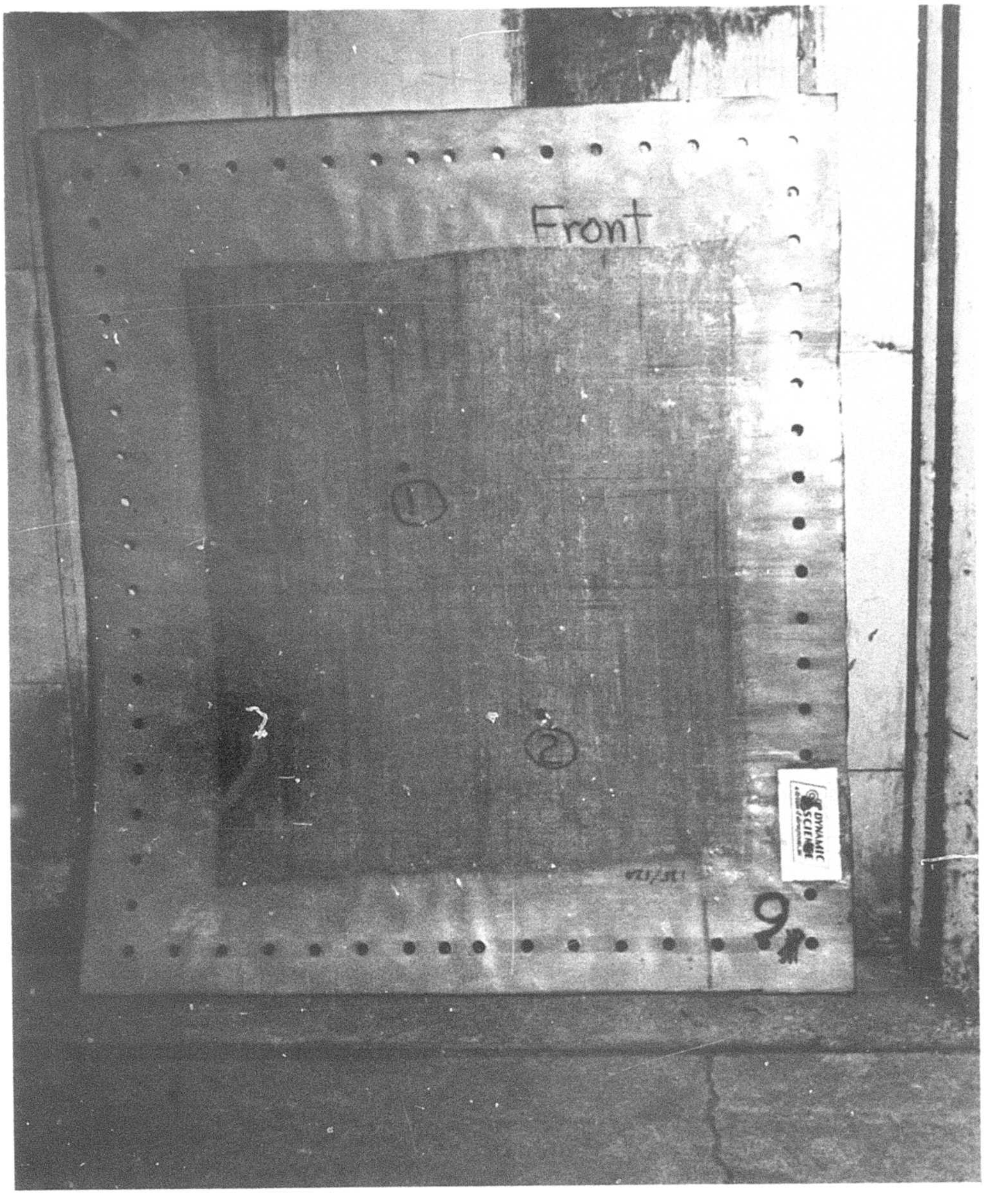

Figure 6. Entrance Test Panel, Shots 1 and 2

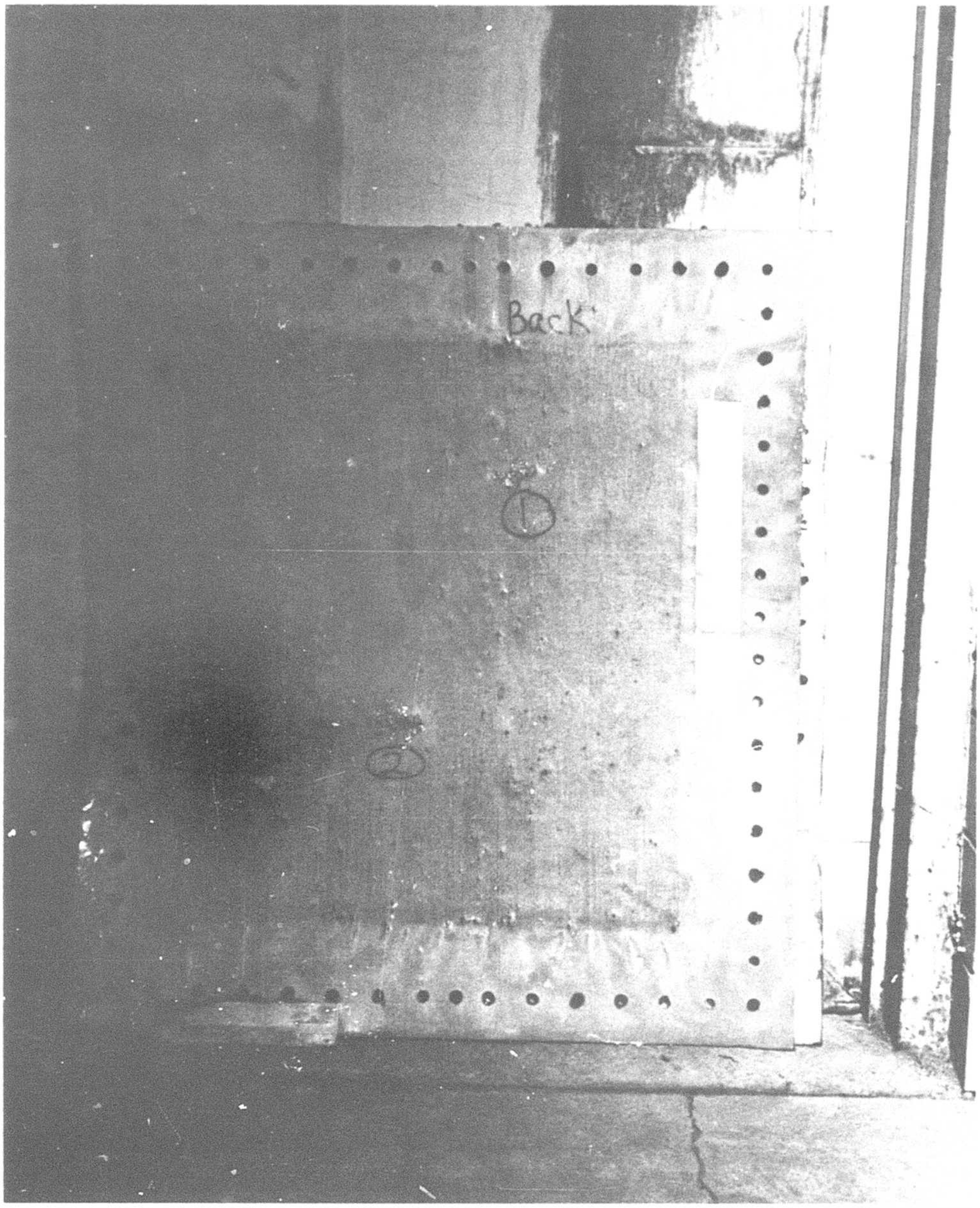

Figure 7. Exit Test Panel, Shots 1 and 2

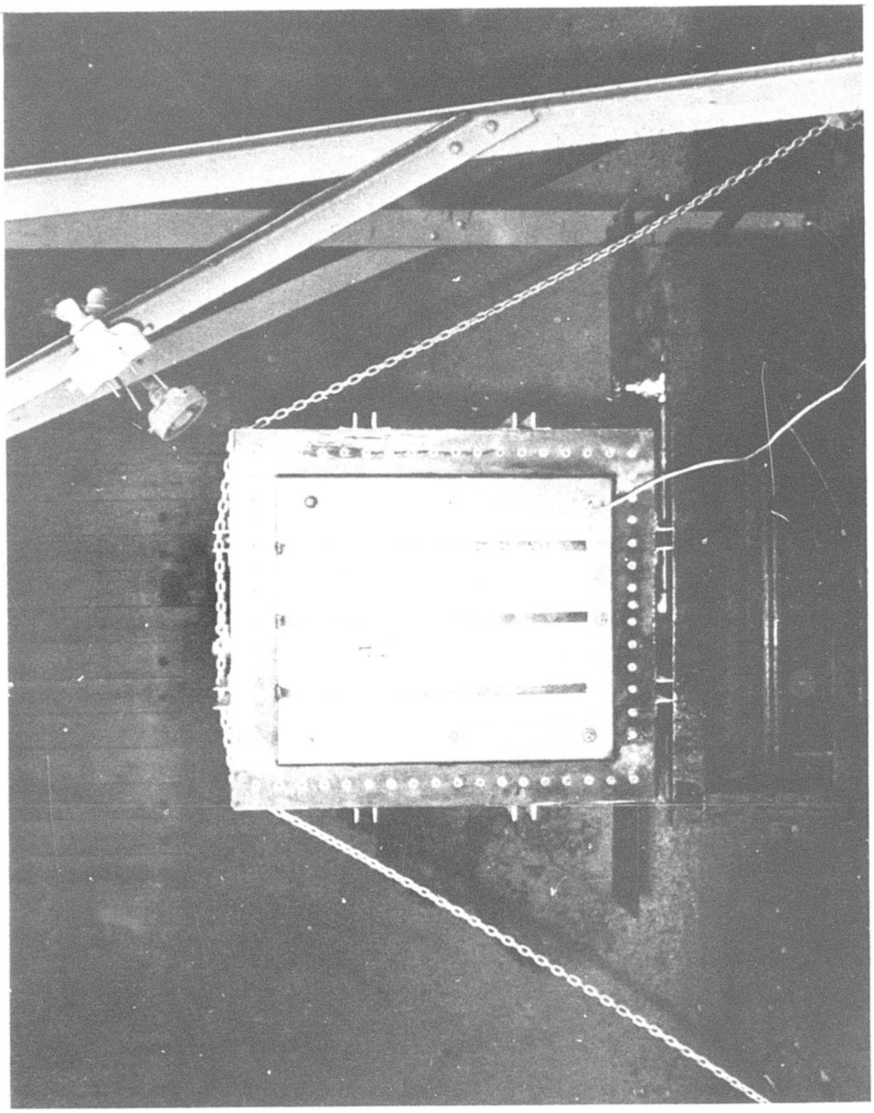

Figure 8. Shot 1 Entrance (.50 Cal. APM2)

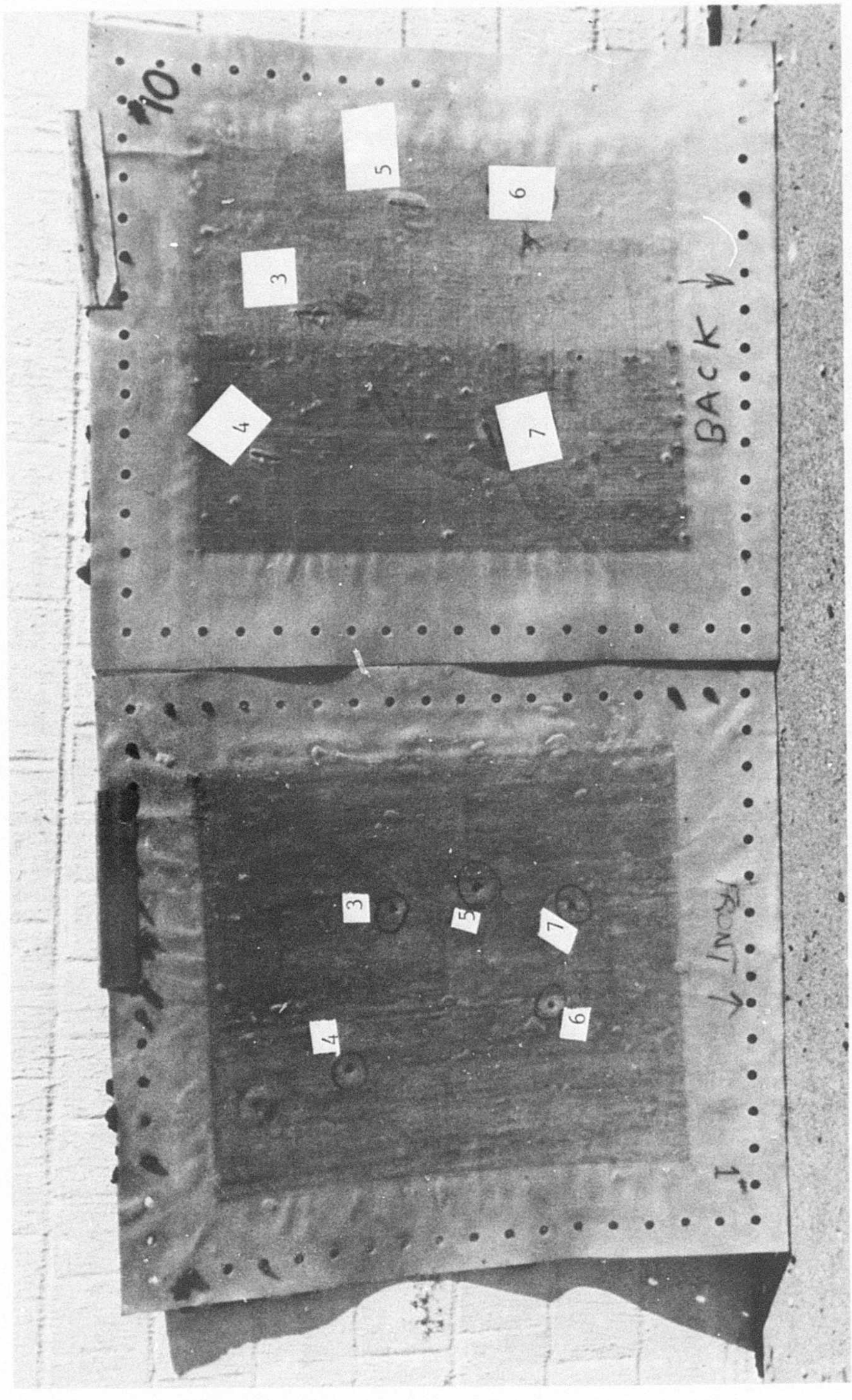

Figure 9. Entrance and Exit Test Panels, Shots 3 - 7

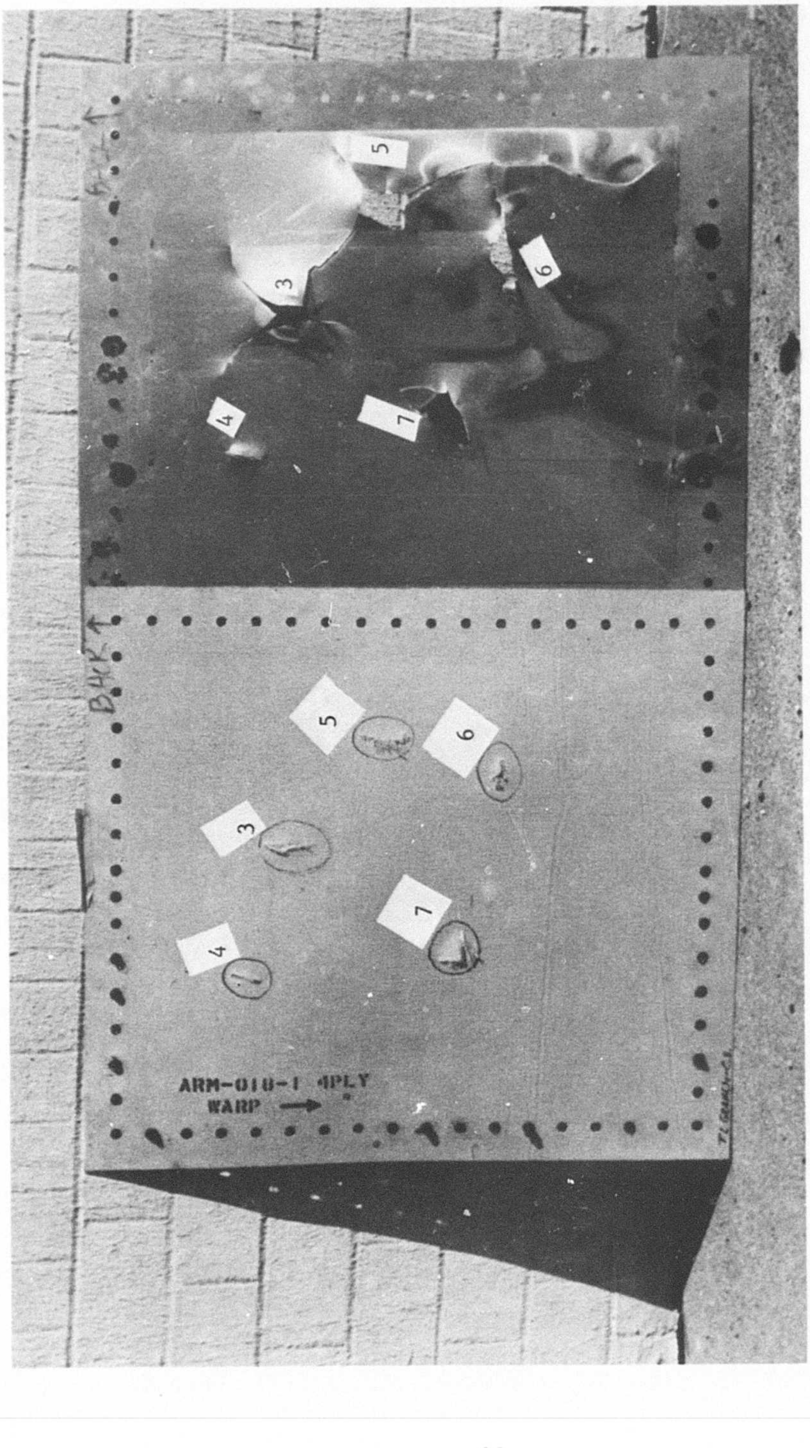

Figure 10. Exit Backing Board and Sheet Metal Panels, Shots 3 - 7

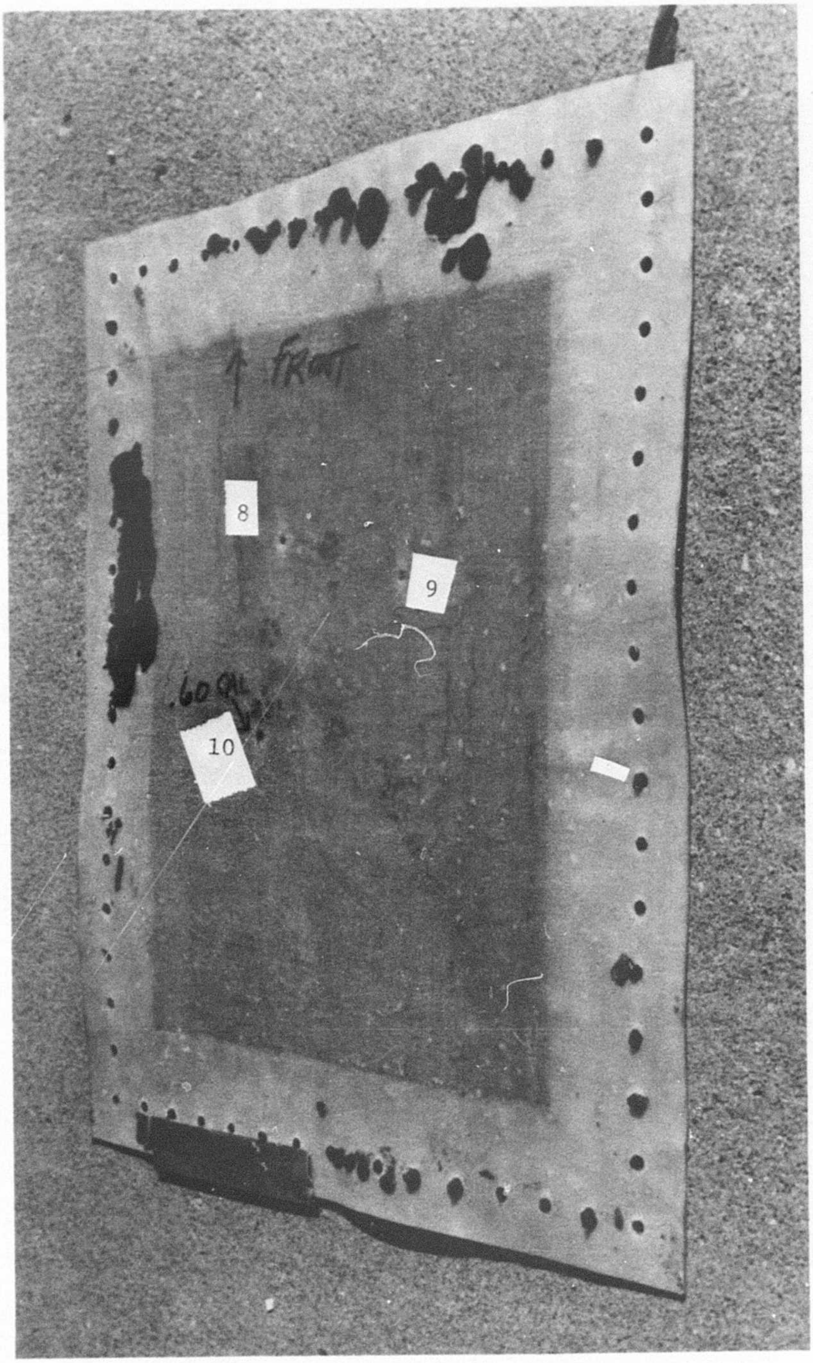

Figure 11. Entrance Test Panel, Shots 8 - 10

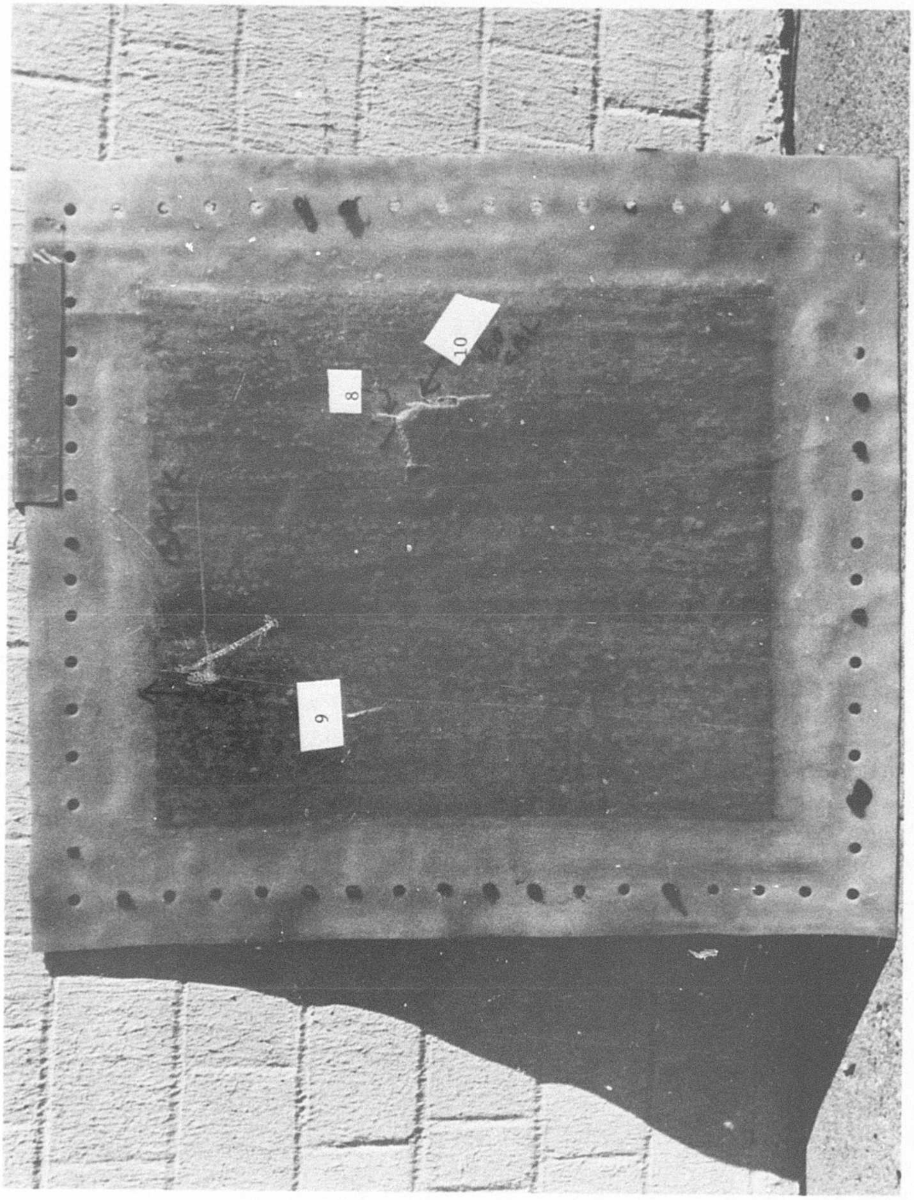

Figure 12. Exit Test Panel, Shots 8 - 10

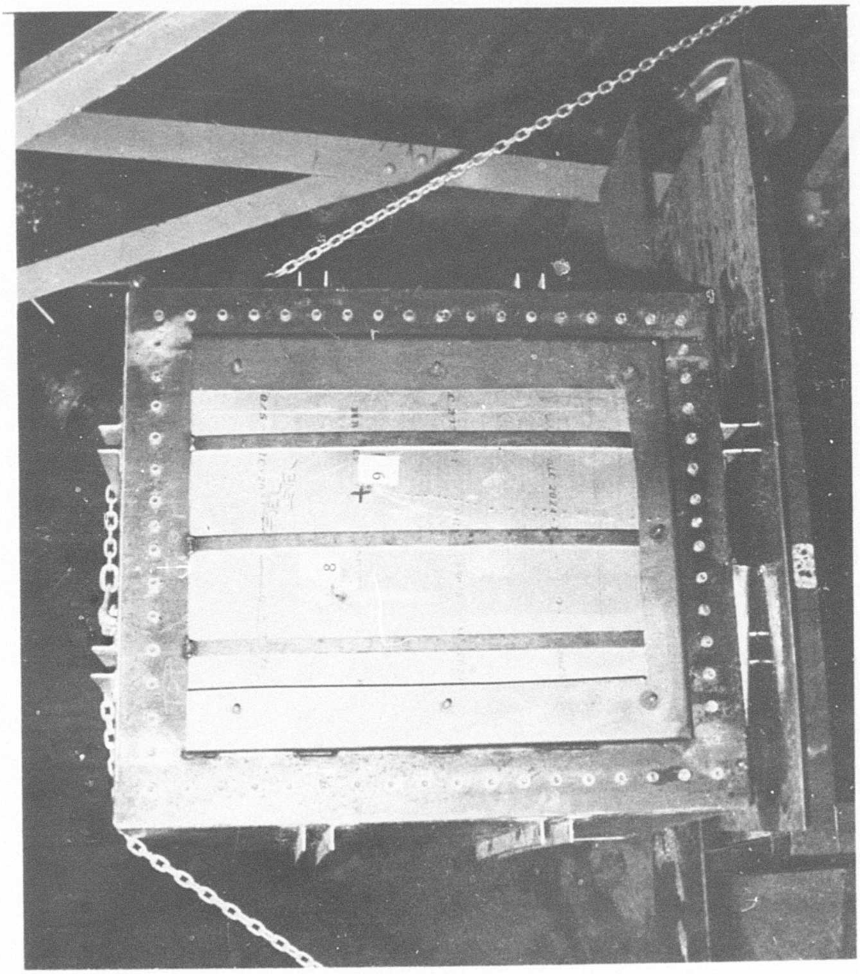

Figure 13. Shot 9 Entrance (Striker Plate Removed, .50 Cal. API)

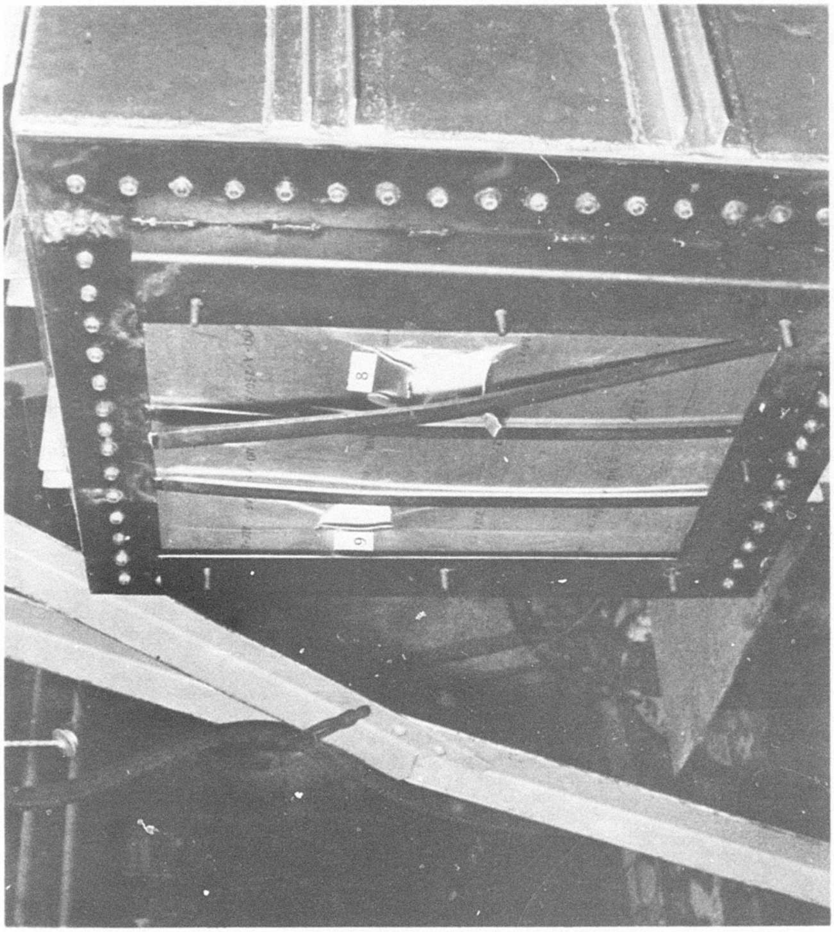

Figure 14. Shot 9 Exit (.50 Cal. API)

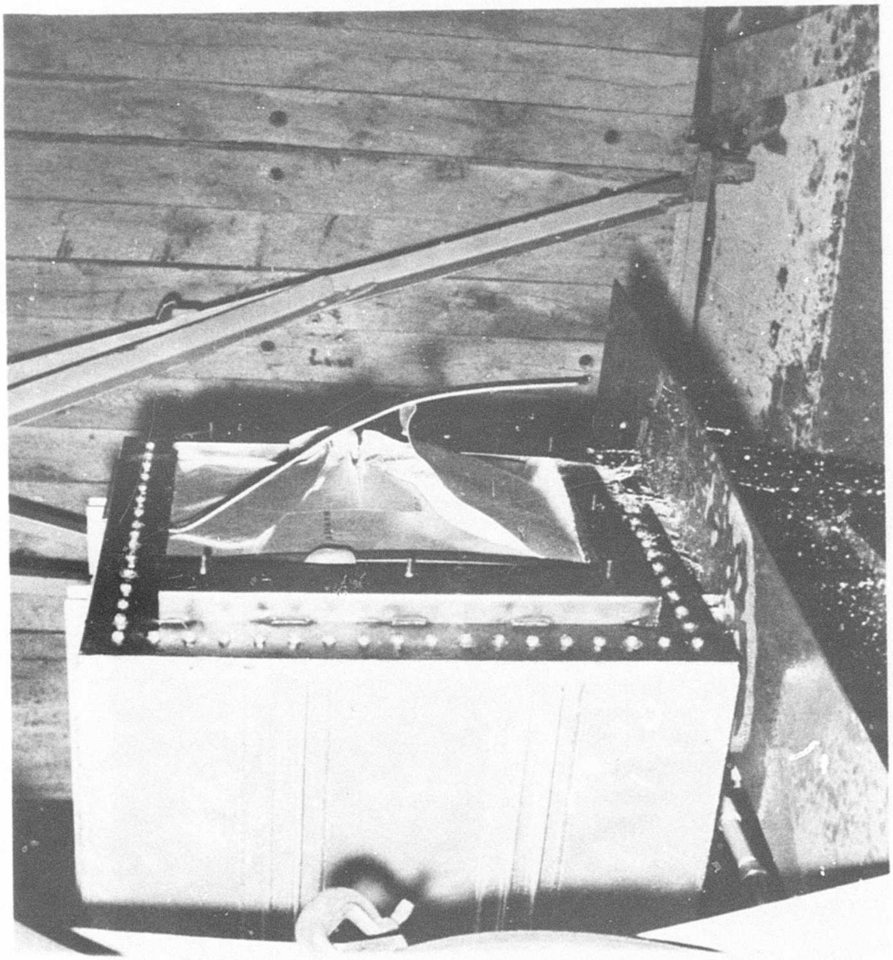

Figure 15. Shot 10 Exit (.60 Cal. Ball)

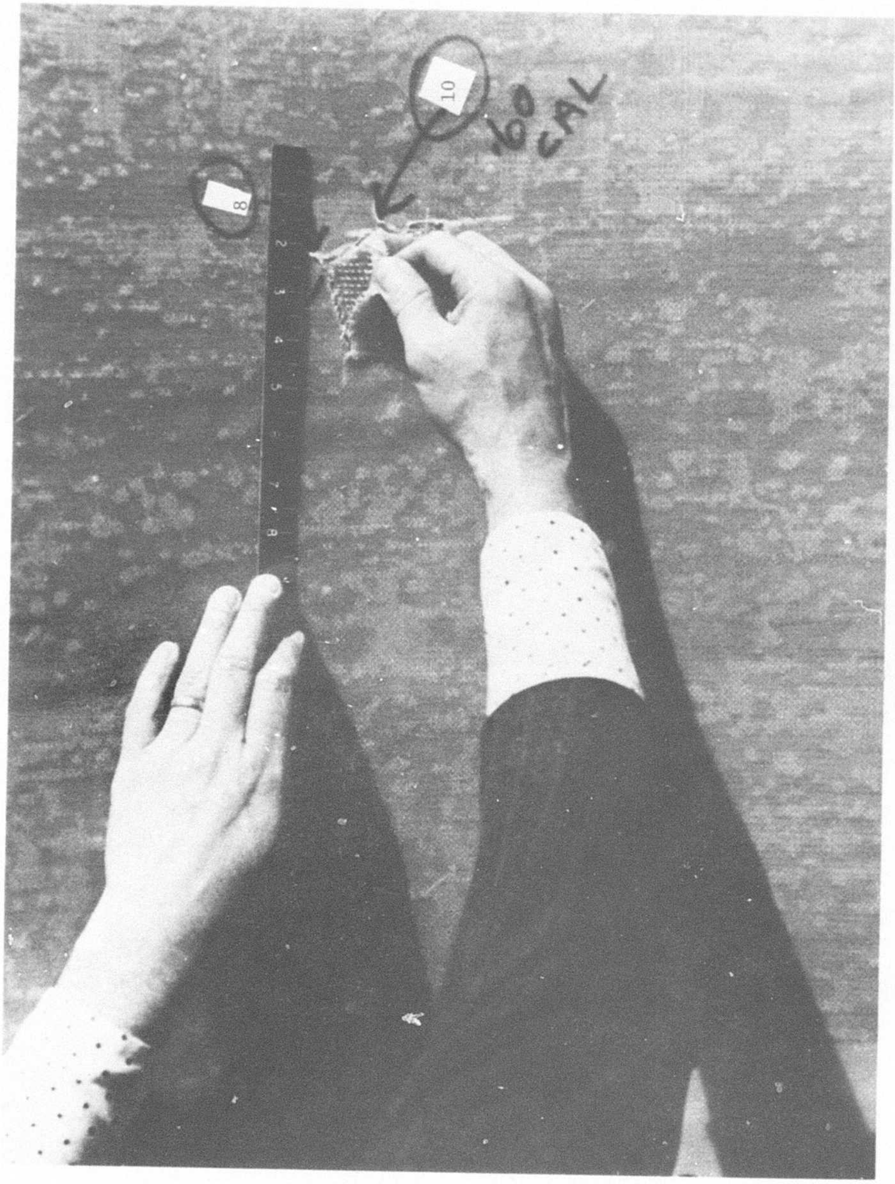

Figure 16. Exit Test Panel, .60 Cal. Shot

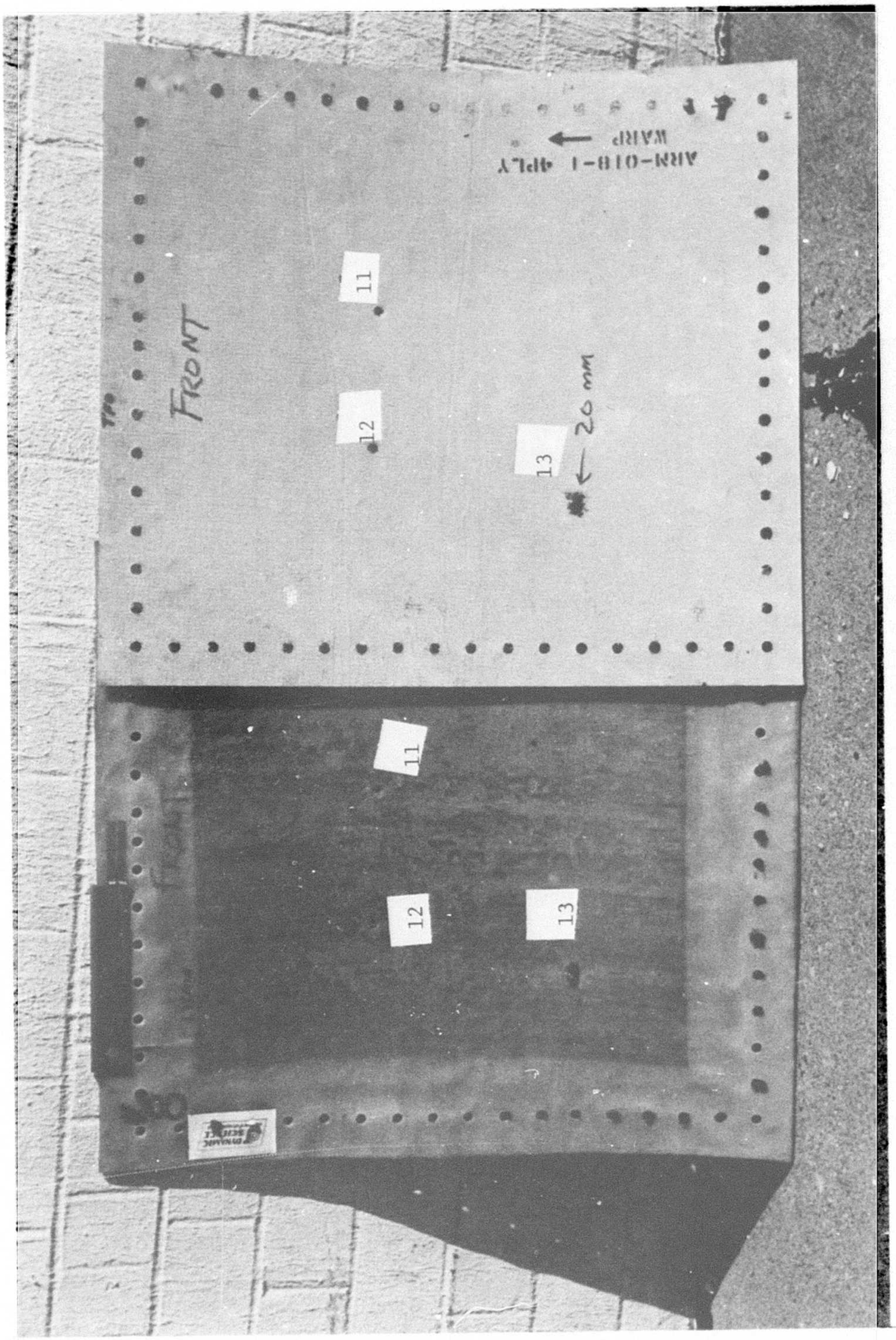

Figure 17. Entrance Test and Backing Board Panels, Shots 11 - 13

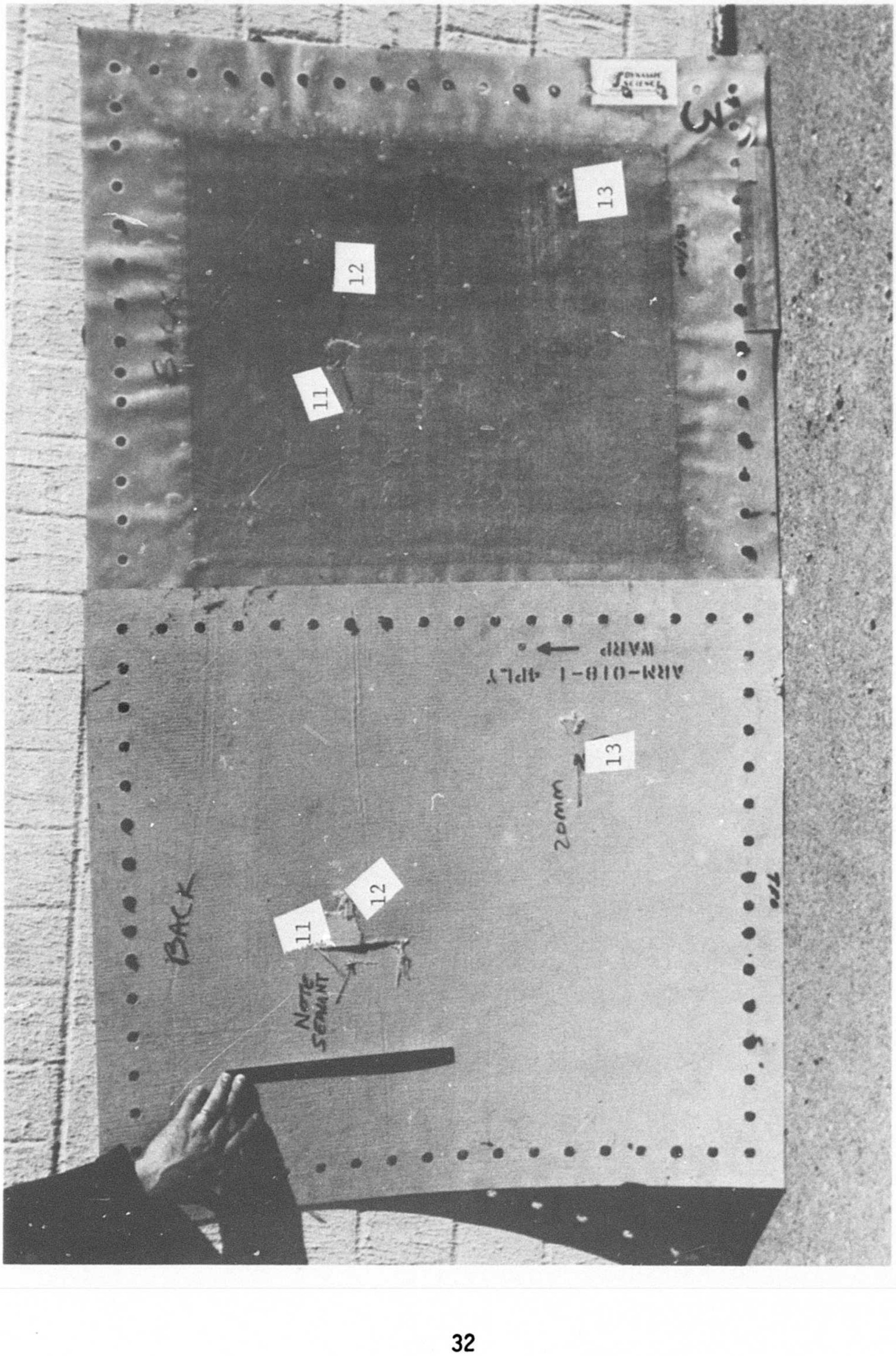

Figure 18. Exit Test and Backing Board Panels, Shots 11 - 13

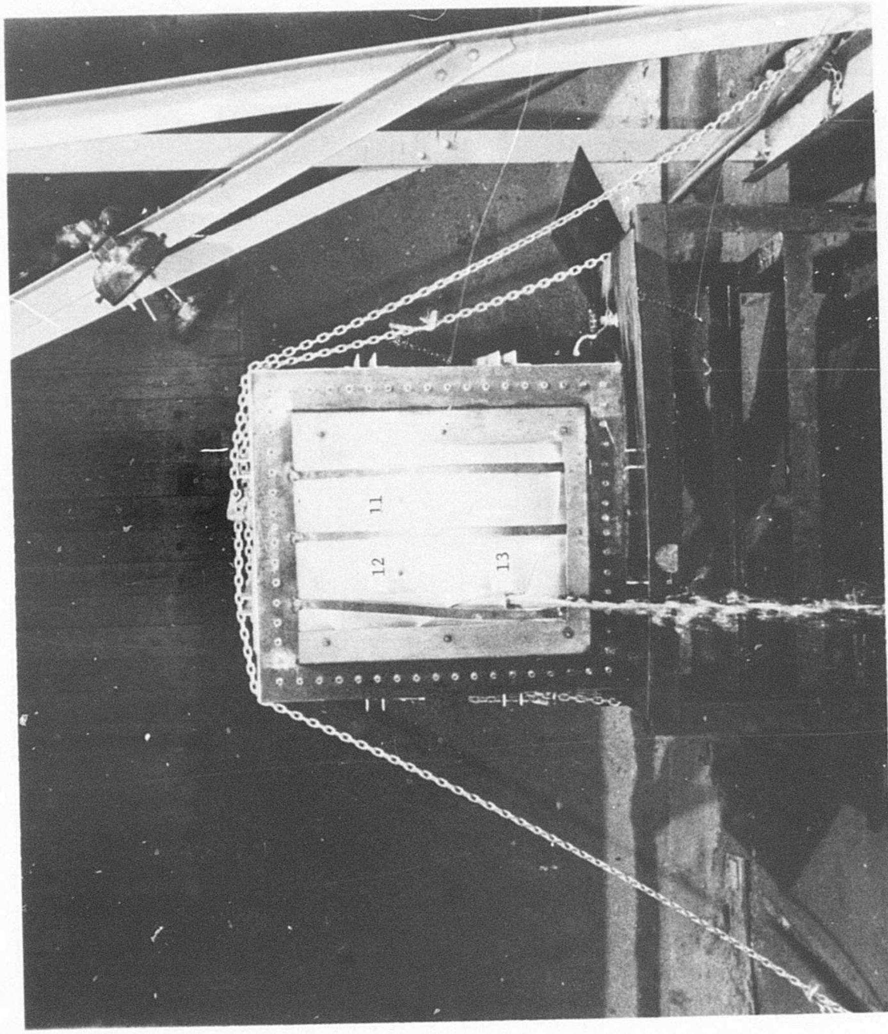

Figure 19. Shot 13 Entrance (20mm. Ball)

APPENDIX A

FUEL ANALYSIS REPORT

SUBMITTED BY	TEST LABORATORY AND LOCATION	ORIGIN OR CONTRACTOR
ASD/ENJPF T.O. REED	AEROSPACE FUELS LABORATORY SFQLA WPAFB OH	

LABORATORY TEST NUMBER	1372
DATE RECEIVED IN LAB	8 June 1973
SPECIFICATION NUMBER	
GRADE NUMBER	JP-4
CONTRACT NUMBER	
QUANTITY REPRESENTED (GALS)	
TYPE CONTAINER AND NUMBER	
SAMPLE NUMBER	
REMARKS (PERTAINING TO SAMPLE AS RECEIVED)	GUNFIRE TESTS
LABORATORY DATA	
GRAVITY °A.P.I.	55.8
WSIM	
APPEARANCE	
COLOR	
ODOR	
WATER REACTION	
FREEZING POINT °F	
CORROSION	
EXISTENT GUM, MG/100 ML	9.0
POTENTIAL GUM, MG/100 ML	
OXIDATION PPT. MG/100 ML	
DOCTOR TEST	
MERCAPTAN SULFUR, % WT.	
TOTAL SULFUR, % WT.	
VAPOR PRESSURE, P.S.I. @ 100° F	2.3
ANILINE POINT °F	
ANILINE GRAVITY CONSTANT OR B.T.U.	
SMOKE POINT MM (OR SMOKE VOL INDEX)	
AROMATICS, %	12.2
OLEFINS, %	2.0
[redacted] Neut. No.	.007
FLASH POINT, °F	
KNOCK RATING	LEAN RICH
TOTAL SOLIDS, MG/GAL	
FIBROUS MATERIAL PER/QT	
VISIBLE FREE WATER ML/GAL	
NONCOMBUSTIBLE SOLIDS MG/GAL	
TOTAL WATER, PPM BY VOL. BY KARL FISCHER	
THERMAL STABILITY, TUBE DEPOSIT CODE NO.	
THERMAL STABILITY, PRESSURE DIFF. (IN. HG.)	
MIL-I-27686 ICING INHIBITOR, % BY VOL	0.057

DISTILLATION				
	IBP °F 141		167 °F	
REMARKS (PERTAINING TO USABILITY AND DISPOSITION OF MATERIAL)	10% 215		221	
	20% 236		275	
	40%		290	52.0
	50% 287		370	73.5
MATERIAL REPRESENTED BY SAMPLE NO. (IS) (IS NOT) SATISFACTORY FOR USE	90% 440		400	80.0
	10% 50%		470	
No Remarks.	E PT. 482		REC	98.0
	RES % 1.0		LOSS	1.0

APPROVED BY: (NAME AND SIGNATURE OF LAB SUPV)
Thomas J. O'Shaughnessy
Chief, AF Aerospace Fuels Laboratory
Directorate of AF Aerospace Fuels

AFTO FORM SEP 65 68 SUPERSEDES SEP 63 EDITION WHICH WILL BE USED.

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APPENDIX B

TEST SHEET

SHOT NUMBER 1 (one) DATE 3 April 1973

FUEL TEMPERATURE 46°F OAT 48°F

THREAT .50 Cal APM2 (Straight-in)

CONFIGURATION Backboard/120# self-seal ent and exit/no foam/no metal sheet

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 26" up - 20.5" across --- approx 4" below fuel surface

HIT LOCATION - EXIT 23-1/2" up - 15.5" across --- approx 6.5" below fuel surface

EXTERNAL FIRE XXX (NO)

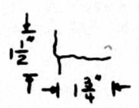
ENTRANCE SEAL AT IMPACT XXX (NO)

EXIT SEAL AT IMPACT XXX (NO)

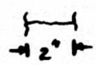
ENTRANCE SEAL AT 2 MIN XXXXX (NO)

EXIT SEAL AT 2 MINUTES XXXXX (NO)

RESULTS: Large Tear (see below) on exit - exit leak described at medium heavy running seep. Entrance was exhibiting some bubbling and looked as if it was trying to seal. Upon teardown, a very small pin hole was observed in entrance wound and exit wound had both chunked out and sealant washout. The exit wound was deformed slightly outward on the panel.



Backboard



Cell Wall

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 2 (two) DATE 3 April 1973

FUEL TEMPERATURE 46°F OAT 48°F

THREAT .50 Cal APM2 (straight-in)

CONFIGURATION Backboard/120# self-seal ent and exit/no foam/no metal sheet

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 15" up - 15" across --- approx 12" below fuel surface

HIT LOCATION - EXIT 12" up - 20.5" across --- approx 15" below fuel surface

EXTERNAL FIRE xX8X (NO)

ENTRANCE SEAL AT IMPACT X8X X8X Possible

EXIT SEAL AT IMPACT X8X (NO)

ENTRANCE SEAL AT 2 MIN (YES) X8X

EXIT SEAL AT 2 MINUTES xX8X (NO)

RESULTS: Large tear (2") on exit - exit may have been slightly better than first shot despite greater fuel head and no support. Exit leak described as medium heavy running seep. Upon teardown the exit was measured - 2-1/2" long and sealant was oozing on both inside and outside of panel.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 3 (three) DATE 5 April 1973

FUEL TEMPERATURE 40°F OAT 41°F

THREAT .50 Cal API M8 (straight-in/non-functioned)

CONFIGURATION .063, 2024 T3 Alum/backboard/150# self-seal ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 25.5" up - 18" across --- 5" below fuel surface

HIT LOCATION - EXIT 25.5" up - 14.5" across --- 5" below fuel surface

EXTERNAL FIRE XXX (NO)

ENTRANCE SEAL AT IMPACT (YES) XXX

EXIT SEAL AT IMPACT xXXXx (NO)

ENTRANCE SEAL AT 2 MIN (YES) xXXx

EXIT SEAL AT 2 MINUTES (YES) xXXx Damp seal

RESULTS: No API activation noticed, very slight leakage at impact on exit, damp seal at exit at 2 minutes. 3.5" vertical tear on backing board at exit. No fuel leakage from test specimen (dry floor). Upon teardown it was noticed that exit was cored slightly.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 4 (four) DATE 5 April 1973

FUEL TEMPERATURE 40°F OAT 41°F

THREAT .50 Cal API M8 (straight-in/non-functioned)

CONFIGURATION Alum sheet/back board/150# ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 24.5" up - 14" across --- 6" below fuel surface

HIT LOCATION - EXIT 25" up - 22" across --- 5.5" below fuel surface

EXTERNAL FIRE ~~YES~~ (NO)

ENTRANCE SEAL AT IMPACT (YES) ~~NO~~ Damp seal

EXIT SEAL AT IMPACT ~~YES~~ (NO)

ENTRANCE SEAL AT 2 MIN (YES) ~~NO~~

EXIT SEAL AT 2 MINUTES ~~YES~~ (NO)

RESULTS: Impact loosened exit seal of shot #3 so fuel was leaking profusely, also leakage from bottom of panels. Exit impacted at crossbar but did not break it. Upon teardown there was not ooozing from wound. NOTE PIECE OF JACKET FOUND ON INSIDE OF EXIT WOUND.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 5 (five)   DATE 5 April 1973

FUEL TEMPERATURE 40°F   OAT 41°F

THREAT .50 Cal APM2 (straight-in)

CONFIGURATION Alum sheet/back board/150# ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 20" up - 21" across --- approx 6" below fuel surface

HIT LOCATION - EXIT 19.5" up - 9" across --- approx 6.5" below fuel surface

EXTERNAL FIRE ~~YES~~ (NO)

ENTRANCE SEAL AT IMPACT (YES) ~~NO~~

EXIT SEAL AT IMPACT ~~YES~~ (NO)

ENTRANCE SEAL AT 2 MIN (YES) ~~NO~~

EXIT SEAL AT 2 MINUTES ~~YES~~ (NO)

RESULTS: Medium heavy seep. Believed exit may have sealed after 7th shot however upon teardown there was no oozing observed at the exit wound.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 6(six)   DATE 5 April 1973

FUEL TEMPERATURE $40^{o}F$ OAT $41^{o}F$

THREAT .50 Cal Ball M2 (straight-in)

CONFIGURATION Alum sheet/back board/150# ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 16" up - 20" across --- approx 9" below fuel surface

HIT LOCATION EXIT 14" up - 11" across --- approx 11" below fuel surface

EXTERNAL FIRE ~~YES~~ (NO)

ENTRANCE SEAL AT IMPACT ~~YES~~ (NO)

EXIT SEAL AT IMPACT ~~YES~~ (NO)

ENTRANCE SEAL AT 2 MIN ~~YES~~ (NO)

EXIT SEAL AT 2 MINUTES ~~YES~~ (NO)

RESULTS: Cross-bar snapped at exit medium heavy seep at entrance and medium stream at exit at 2 minutes. Backing board indicated + shape wound and it was theorized that the cell wall had misaligned at exit. Upon teardown there was no sealant oozing from the wound and wound was slightly cored.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 7 (seven) DATE 5 April 1973

FUEL TEMPERATURE 40°F OAT 41°F

THREAT .50 Cal API M8 (straight-in/functioned)

CONFIGURATION Alum sheet/back board/150# self-seal ent and exit .090 2024-T3 alum and 15 ppi foam in cavity

GUN LOCATION 38 Feet

HIT LOCATION - ENTRANCE 13" up - 12" across --- est 10" below fuel surface

HIT LOCATION - EXIT 16" up - 21" across --- est 7" below fuel surface

EXTERNAL FIRE ~~YES~~x (NO)

ENTRANCE SEAL AT IMPACT ~~YES~~x (NO)

EXIT SEAL AT IMPACT x~~YES~~ (NO)

ENTRANCE SEAL AT 2 MIN xx~~YES~~x (NO)

EXIT SEAL AT 2 MINUTES x~~YES~~x (NO)

RESULTS: Medium heavy seep entrance and exit at 2 minutes. Both entrance and exit were slowing at 6 minutes. At about 15 minutes after shot both entrance and exit sealed. There was some slight oozing upon teardown. There was a poor API functioning based upon soot in foam.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 8 (eight) DATE 10 April 1973

FUEL TEMPERATURE 37°F OAT 39°F

THREAT .50 Cal APM2 (straight-in)

CONFIGURATION Alum sheet/backboard/120# self-seal ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 24" up - 20" across --- approx 5" below fuel surface

HIT LOCATION - EXIT 21-1/2" up - 11-1/2" across --- approx 7.5" below fuel surface

EXTERNAL FIRE XXXXX NO

ENTRANCE SEAL AT IMPACT XXXX NO

EXIT SEAL AT IMPACT XXX NO

ENTRANCE SEAL AT 2 MIN XXX NO

EXIT SEAL AT 2 MINUTES XXX NO

RESULTS: L-shaped tear in backing board at exit medium seep entrance and medium heavy seep at exit at 2 minutes. Entrance was slowing considerably;tore cross bar at exit.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 9 (nine) DATE 10 April 1973

FUEL TEMPERATURE 37°F OAT 39°F

THREAT .50 Cal API (straight-in/functioned)

CONFIGURATION .090 Function plate, no foam, same as shot 8

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 23" up - 13" across --- approx 6" below fuel surface

HIT LOCATION - EXIT 23" up - 23-1/2" across --- approx 6" below fuel surface

EXTERNAL FIRE ~~xxxx~~ NO

ENTRANCE SEAL AT IMPACT ~~xxxx~~ NO

EXIT SEAL AT IMPACT ~~xxxx~~ ~~xxxx~~ Possible

ENTRANCE SEAL AT 2 MIN ~~xxxxx~~ NO

EXIT SEAL AT 2 MINUTES YES ~~xxxx~~

RESULTS: Thin stream at impact at entrance which slowed to very heavy seep and no further slowing of seep occurred. This shot affected the first shot and caused it to leak more.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 10 (ten) DATE 10 April 1973

FUEL TEMPERATURE $37^{o}F$ OAT $39^{o}F$

THREAT .60 Cal Ball

CONFIGURATION Alum sheet/backboard/120# self-seal ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 17" up - 21" across --- approx 10" below fuel surface

HIT LOCATION - EXIT 21-1/2" - 12" across --- approx 5.5" below fuel surface

EXTERNAL FIRE ~~YES~~ NO

ENTRANCE SEAL AT IMPACT ~~YES~~ NO

EXIT SEAL AT IMPACT ~~YES~~ NO

ENTRANCE SEAL AT 2 MIN ~~YES~~ NO

EXIT SEAL AT 2 MINUTES ~~YES~~ NO

RESULTS: Medium stream at entrance - "gusher" at exit. Exit shot was at same point as first shot. Very severe tearing of both exit cell wall and exit backing board. Broke retaining chain and cross bars front and back.

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 11 (eleven) DATE 12 April 1973

FUEL TEMPERATURE 41°F OAT 49°F

THREAT .50 Cal Ball M2 (straight-in)

CONFIGURATION Alum/back board/120# self-seal ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 22" up - 13" across --- approx 7.5" below fuel surface

HIT LOCATION - EXIT 22-1/2" up - 19-1/4" across --- approx 7.0" below fuel surface

EXTERNAL FIRE ~~YES~~ NO

ENTRANCE SEAL AT IMPACT ~~YES~~ NO

EXIT SEAL AT IMPACT ~~YES~~ NO

ENTRANCE SEAL AT 2 MIN YES ~~NO~~

EXIT SEAL AT 2 MINUTES ~~YES~~ NO

RESULTS: Very slight seep at entrance which eventually damp sealed. Heavy stream at exit and bad tear in backing board at exit. (see below)

back board tear

APPENDIX B (continued)

TEST SHEET

SHOT NUMBER 12 (twelve)   DATE 12 April 1973

FUEL TEMPERATURE 41°F   OAT 49°F

THREAT .50 Cal API M8 (straight-in/functioned)

CONFIGURATION Alum external sheet front/same as shot 11

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 21-1/2" up - 20-3/4" across --- approx 7-1/4" below fuel surface

HIT LOCATION - EXIT 23-1/2" up - 17" across ---approx 5-1/4" below fuel surface

EXTERNAL FIRE ~~YES~~ NO

ENTRANCE SEAL AT IMPACT ~~YES~~ NO

EXIT SEAL AT IMPACT ~~YES~~ NO

ENTRANCE SEAL AT 2 MIN YES ~~NO~~

EXIT SEAL AT 2 MINUTES ~~YES~~ NO

RESULTS: Exit occurred in close proximity to shot #11;a heavy stream resulted from both shot #11 and Shot #12 exits. Very slight seep at entrance which eventually damp sealed.

back board tear

APPENDIX B (concluded)

TEST SHEET

SHOT NUMBER 13 (thirteen) DATE 12 April 1973

FUEL TEMPERATURE 41°F OAT 49°F

THREAT .20 mm TP

CONFIGURATION Alum/back board/120# self-seal ent and exit

GUN LOCATION 38 feet

HIT LOCATION - ENTRANCE 12" up - 23" across --- approx 12.5" below fuel surface

HIT LOCATION - EXIT 11-1/4" up - 8" across --- approx 13.25" below fuel surface

EXTERNAL FIRE ~~YES~~ NO

ENTRANCE SEAL AT IMPACT ~~YES~~ NO

EXIT SEAL AT IMPACT ~~YES~~ NO

ENTRANCE SEAL AT 2 MIN ~~YES~~ NO

EXIT SEAL AT 2 MINUTES ~~YES~~ NO

RESULTS: Heavy gushing leak at entrance, medium heavy stream at exit. Approx 1" diameter hole at entrance - entrance shot hit cross-bar and removed portion of cross bar into wound. Exit hit cavity metal and bent it.

REFERENCES

1. R. C. Kohrn, W. R. Birkey, and R. L. Butz, Improved Materials for Aircraft Self-Sealing Fuel Cell Systems, AFML-TR-68-356, Part I, November 1968.

2. R. C. Kohrn, W. R. Birkey, and J. D. Ballentine, Improved Materials for Aircraft Self-Sealing Fuel Cell Systems, AFML-TR-68-356, Part II, March 1971.

3. R. C. Kohrn, W. R. Birkey, and F. Gerligs, Improved Materials for Aircraft Self-Sealing Fuel Cell Systems, AFML-TR-72-56, December 1972.

4. J. D. Ballentine, F. Geerligs, J. R. Kulesia, Exploratory Development Leading to Improved Materials for Self-Sealing Aircraft Fuel Systems, AFML-TR-73-248, December 1973.

5. J. K. Klein, Personal Communications, March 1970.

6. L. Mahood, Personal Communication, March 1973.

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